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(54) Title: NERVE PROCESS GROWTH MODULATORS

(57) Abstract

Nerve process growth modulation can be achieved using derivatized cyclodextrins. Processes for making sulfated and aminated β-cyclodextrin derivatives are also described in which a compound of the formula $R''_2 NCH X'^+ X'^-$ where R'' is an alkyl containing 1-5 carbon atoms and X' is selected from bromine and iodine is used to halogenate the cyclodextrin.

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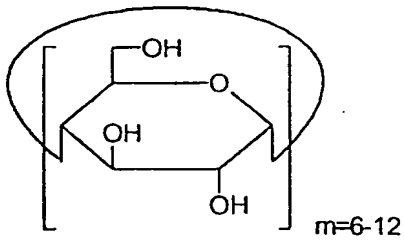
NERVE PROCESS GROWTH MODULATORS

FIELD OF INVENTION

This invention relates to nerve process growth modulation using novel cyclomalto-oligosaccharides, commonly known as cyclodextrins, and to methods making the novel oligosaccharides. More particularly this invention relates to the use of novel sulfated and aminated β-cyclodextrin derivatives as potent modulators of nerve process growth.

BACKGROUND OF INVENTION AND PRIOR ART

Cyclodextrins (CD or CDs) are cyclic oligosaccharides consisting of at least six and up to about twelve ∝(1,4) linked D-glycopyranose units. These compounds have the formula



The cyclic nature of CDs leads to a toroidal shape with a primary face (consisting of primary hydroxyl moieties at C_6), a secondary face (consisting of secondary hydroxyl moieties at C_2 and C_3) and a cavity which is normally considered to be hydrophobic in nature. The external surface of the molecule is more hydrophilic.

The nature of the cavity results in the ability of CDs to form non-covalent inclusion complexes in which, most commonly, an added but separate biologically active molecule is contained within the toroidal cavity. Numerous such complexes have been described which find utility as pharmaceuticals, veterinary compounds, cosmetics, food and flavour additives and the like. These complexes have in common the feature that the cyclodextrin is a "carrier" for a separate active molecular entity modification and derivatization of cyclodextrins has also been reported in order to alter the properties of cyclodextrin as a carrier (or otherwise encapsulating) molecule. Typical of such derivatives are the CD sulfates and other water soluble derivatives described in U.S. Patent 5,019,562, issued 28 May 1991 to Folkman et al. The present invention is not, however, concerned with CDs as "carriers" in which complexes are formed, but rather with the concept that the CD is a molecular scaffold in which a number of pendant groups may be attached to the primary and secondary faces. For example, in γ-cyclodextrin, there are eight points of attachment on the primary face and sixteen on the secondary face. In a homogeneous derivative, all primary

face sites would have an identical pendant chemical group covalently attached, and all secondary face sites would have identical, but different from those on the primary face, pendant chemical groups attached.

The primary face pendant groups are designed to confer biological activity on the derivatized CD molecule itself. The secondary face pendant groups are designed specifically to alter the properties, such as solubility, membrane permeability and bioavailability, of the derivatized cyclodextrin. The pendant groups on the primary face may be chosen to result in a derivatized CD which is either ionic or cationic at any pH in aqueous solution. For example, nitrogen-containing groups may bear a positive charge whereas sulfur-containing groups may carry a negative charge.

Some derivatives of CD, bearing pendant groups at the primary face, prepared as homogeneous CD derivatives have been previously described. Similarly, amine nitrite and sulfonate derivatives of CDs have also been described. However, the methods of making these compounds generally require arduous purification steps and are generally unsatisfactory.

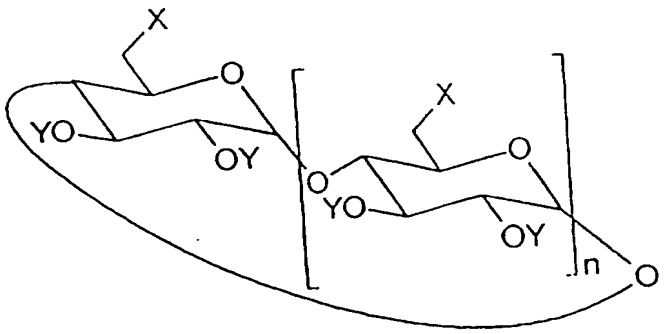
OBJECT OF INVENTION

It is one object of the present invention to provide an improved process for preparing homogeneous derivatives of cyclodextrins.

Another object of this invention is to provide small molecule proteoglycan modulators of nerve process growth.

BRIEF STATEMENT OF INVENTION

Thus, by one aspect of this invention there is provided a process for producing homogeneous cyclodextrin derivatives of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

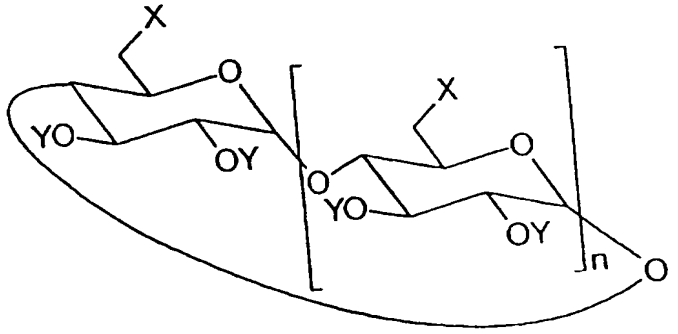
Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium;

comprising reacting a cyclodextrin as defined above but bearing free hydroxyl groups at the carbon-6 position with a compound of the formula:

$$R''_2 NCH X'^+ X'^-$$

where R˝ is an alkyl containing 1-5 carbon atoms; and X˙ is a halogen selected from the group consisting of bromine and iodine, so as to produce a halogenated derivative, and converting said halogenated derivative to a selected said homogeneous cyclodextrin derivative by substitution or exchange of said X˙ at carbon 6.

By another aspect of this invention there is provided a homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 3 to 12;

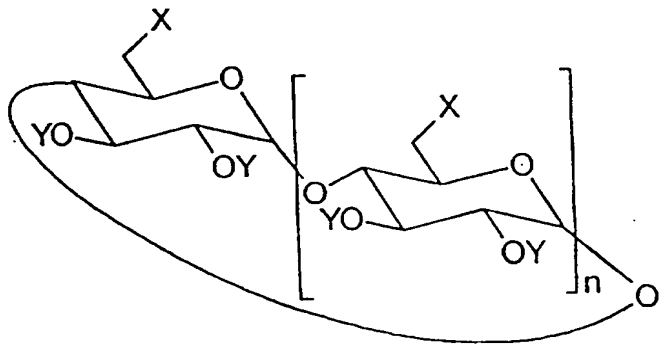
X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen

atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;
R^3 is H or R;
Q is an anionic counterion; and
Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium.

By another aspect of this invention there is provided a method for modulating nerve process growth comprising administering to a patient in need thereof a homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 5 to 12;
X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;
Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;
where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;
R^3 is H or R;
Q is an anionic counterion; and
Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium in admixture with a pharmaceutically acceptable carrier therefore.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a graph illustrating inhibition of neurite growth by SPAβCD in solution. Enriched sensory neurons from ED8 chick DRG were cultured on PDL in the presence of 1ng/ml NGF and the SPAβCDs in solution at the indicated final concentrations. Neurite growth was scored blind at 18-24 hours after seeding the cells. Results are expressed as a

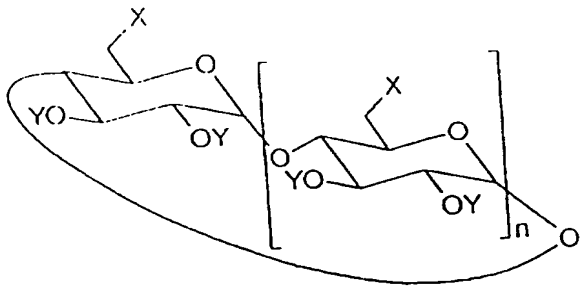
percent of control (no additives) and are the mean of two experiments (quadruplicate determinations). Error bars represent standard deviation from the mean.

Figure 2 is a graph illustrating adhesion of PC12 cells to treated plastic. The wells of a 96 well FALCON tissue culture plate were treated overnight with aqueous solutions (at the indicated concentration) of the SPAβCDs. After two washes in sterile distilled water, PC12 cells were seeded in serum-free RPMI and allowed to adhere for 60 minutes at 4C. After removing medium and washing the wells with phosphate buffered saline, the number of adherent cells was determined by assaying for cellular acid phosphatase. The results are expressed as a factor of control -i.e. the number of cells adhering to untreated plastic, and are the results of two experiments (n=6 experiment) and the error bars represent s.e.m.

Figure 3 is a graph illustrating support of neurite growth by ED8 DRG neurons on immobilized SPAβCDs. The wells of a Terasaki plate were coated overnight with the SPAβCDs at the indicated concentration. After washing the wells twice with sterile distilled water and once with culture medium, ED8 chick DRG sensory neurons were seeded into the wells (1000 cells per well) in the presence of 1ng/ml NGF. Wells were scored blind for % neurite bearing cells and results expressed as a factor of neurite growth on untreated plastic. The results are the mean of three experiments (n=4 per experiment) and error bars represent s.e.m.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

The CD derivatives contemplated for preparation by the present invention have the following general formula:



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen

atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium.

As will be appreciated, these CD derivatives are homogeneous, all primary face sites have covalently attached, identical, pendant groups and all secondary face sites have pendant groups identical to each other but different from those on the primary face sites.

The above compounds can be produced, according to the present invention, by halogenation of CD or a derivative of CD modified at the secondary face in which all carbon-6 positions of the primary face are halogenated. The essential feature of this process is the use of a reagent of the formula

$$R''_2 NCH X'^{+} X'^{-} \qquad (2)$$

where R˙ is an alkyl containing

1-5 carbon atoms; and

X˙ is selected from bromine and iodine.

Use of this reagent reduces the number of processing steps, raises the yield of product and produces a homogeneous product.

The starting material for halogenation may be a CD or CD derivative modified at the secondary face. Thus, any CD bearing pendant groups Y (as described above) but underivatized at the primary face, that is bearing free hydroxyl groups at the carbon-6 position, may be converted to halogenated CD derivatives using reagent 2. These conversion products are described by the same formula as (1) with the exception that X is either iodine or bromine. These halogenated CD derivatives can then be converted to the desired cationic or anionic CD derivative by substitution or exchange of the halogen at carbon-6 with a different, selected, chemical group. For example, anionic sulfonate CD derivatives requires exchange of halogen with a sulfonyl group (SO_3^-) and may be effected by reacting the halogenated CD with an alkali metal sulfite salt, under pressure, to yield a homogeneous CD derivative in which all the primary face carbon -6 positions bear a sulfonyl group. In addition, sulfonate CD derivatives may be obtained by reaction of a selected amino CD or derivative with propyl sultone in an appropriate solvent. Cationic CD derivatives can be prepared by any one of four methods. Firstly, the halogenated CD may be reacted with an alkali metal azide salt and reduced with triphenylphosphine followed by basic work up to yield a homogeneous CD derivative in which all primary face carbon-6 positions bear an amino(NH_2) group. Acidification of the amino CD derivative allows

isolation of a cationic amino CD derivative as a salt. The amino CD derivative may also be reacted with an aldehyde or acetal to yield an imino CD derivative, a Schiff base, in which all primary face carbon-6 positions bear a nitrogen doubly bonded to carbon, in an imine functionality. The aldehyde or acetal is selected so as to yield a product conforming to formula (1).

Further reductions of the imine functionality of the Schiff base produces a homogeneous amine CD derivative in which all primary face carbon-6 positions bear a nitrogen which is part of an amine functionality. The imino or amino CD derivatives may be acidified to produce a salt, which may contain counterions to the cationic CD derivative as described in formula (1).

Secondly, the halogen of a halogenated CD derivative may be exchanged with a nitrile or cyano group (-CN) by reaction with an alkali metal cyanide salt to yield a homogeneous cyano-CD derivative in which all the primary face carbon-6 positions bear a nitrile group. Reduction of the nitrile group yields a homogeneous amino CD derivative in which all the primary face carbon-6 positions bear an aminomethylene group ($-CH_2NH_2$). Acidification of the aminomethylene CD derivative isolates a cationic amino CD derivative as a salt. Alternatively, further reaction of the aminomethylene CD derivative, as described above for the amino CD derivative, yields cationic CD derivatives conforming to formula (1).

Thirdly, a halogenated CD derivative may be reacted with thiourea to produce a thiouronium CD derivative in which all primary face carbon-6 positions bear a thiouronium ($SC(NH_3)_2$ X; where X is I or Br) group. Acidification results in isolation of a thiouronium salt of the CD derivative. Hydrolysis or alcoholysis of the thiouronium salt gives a homogeneous mercapto CD derivative in which all the primary face carbon-6 positions bear a mercapto or thiol group (-SH). Cationic derivatives of formula (1) can be prepared from the mercapto CD derivative by reaction with an alkyl halide (where the halide is Cl, Br or I). The product of this reaction can be isolated as a homogeneous mercaptoamine CD derivative, conforming to formula (1) in which all primary face carbon-6 positions bear a sulfur which is part of a sulfide functionality. The alkyl group of the alkyl halide may contain nitrogen, unsaturated and aryl groups, but is limited to conform to a final product described by formula (1).

Acidification produces a mercaptoamine CD derivative salt, which may contain counterions to the cationic CD derivative, as described in formula (1).

Fourthly, a halogenated CD derivative may be reacted with an excess of the appropriate amine, H_2NR, $HNRR^1$, to yield a product corresponding to formula (1).

Example 1

Per-2,3-dimethyl-per-6-amino-6-deoxy-CD HC1 salt (Formula 1: X=NH_3Cl; Y=CH_3; n=5-7). The bromination reagent, $[Me_2NCHBr]^+Br^-$ was prepared by addition of Br_2 dropwise

to triphenylphosphine in DMF. The reaction mixture was cooled to 0°C and allowed to stand forming a precipitate, which was filtered to isolate the imminium reagent as a white crystalline solid. After washing with cold DMF, the solid was dissolved in DMF and the CD (freshly dried) added to the solution. The mixture was heated for 18 hr at 80°C with a drying tube, allowed to cool and an aliquot of sodium methoxide solution (3M) added. Solvent was removed at reduced pressure to yield the product as a syrup. Water was added and after stirring the precipitate was filtered and washed with water to yield the per-6-bromoCD product in 95-98% yield.

Per-6-azidoCD ws obtained from reaction of the per-6-bromoCD with sodium azide (1.3n eq.; where n=6-8) in DMF at 65°C for 24hr. Solvent was evaporated and the residue added to water. The precipitate was filtered and washed with acetone to give product in 94-98% yield.

The per-2,3-dimethyl-per-6-amino-6-deoxyCD derivative of βCD (MeβCDA) was prepared by addition of methyl iodide (40 eq.) to a solution of per-6-azido-6-deoxyβCD and NaH (30 eq.) in DMF. The reaction mixture was stirred for 24hr at R.T., methanol added and the mixture concentrated under vacuum. Ice-water was added and the resulting precipitate collected and dried. MeβCDA was obtained as the per-6-ammonium chloride salt by reduction of the azide with triphenylphosphine in dioxane followed by work-up with ammonium hydroxide solution and isolation as previously described. The product was obtained as a white solid in 92% isolated yield, calculated from the azide. These synthetic strategies yield CD derivatives, homogeneous by ^{1}H and ^{13}C NMR spectroscopy (Fig. 1) without recourse to chromatography.

Example 2

Per-6-[methylene-2-pyridyl-amino]-6-deoxy-CD (Formula 1: X=$NHCH_2C_5H_4N$; Y=H; n=5-7) was prepared from the corresponding per-6-azido-6-deoxyCD. Per-6amino-6-deoxyCD was obtained by reduction of the azide with triphenylphosphine (3n eq.) in DMF with stirring at room temperature for 1.5hr followed by dropwise addition of concentrated ammonium hydroxide solution to the reaction mixture and continued stirring for 15hr. Solvent was evaporated and ethanol added to the residue. The resulting precipitate was filtered, washed with ethanol and added to a small volume of water. Careful acidification with dil. HC1 to pH 4 gave a solution of the water-soluble CD-ammonium chloride salt from which contaminants can be removed by filtration. The CD-ammonium salt may be isolated by reduction of the resulting filtrate under vacuum and subsequent drying in an isolated yield of 87-92%. Alternatively, the per-6-amino-6-deoxyCD, may be obtained from the initial isolated precipitate by washing with successive portions of benzene and drying under high vacuum.

To a suspension of per-6amino-6-deoxyCD (0.448mmol) in dry DMF (5ml) was added pyridine-2-carboxaldehyde (7.5 eq.). The suspension was stirred for 3hr at room temperature, over which time an homogeneous orange solution resulted. Addition of acetone gave a precipitate which was filtered, washed and dried under vacuum to give the per-6-imino-6-deoxyCD derivative in 75-82% isolated yield. Reduction of the CD-imine was facile on stirring with sodium borohydride (10 eq.) in methanol (8ml) at -78°C for 3hr.

Table Spectroscopic data for CD derivatives: Using Formula 1: 1 (X=Br; Y=H) 2 (X=N_3; Y=H) 3 (X=NH_3Cl; Y=H) 4 (X=CN; Y=H) 5 (X=SCN_2H_4Br; Y=H) 6 (X=SH; Y=H) 7 (X=NH_3Cl; Y=Me) 8 (X=$NHCH_2CH_2NMe_2.2HCl$; Y=H) 9 (X=$NHCH_2C_5H_4N.HCl$; Y=H).

		^{13}C NMR shifts (ppm)							
	FAB-MS[a]	C1	C2	C3	C4	C5	C6	C(N)	solvent
1α	1351	101.84	71.62	72.49	84.70	70.66	34.76	-	DMSO
2α	1096[c] *1047*	101.81	71.61	72.76	83.44	70.45	51.40	-	DMSO
3α	967[b]	101.37	71.37	72.66	82.56	68.04	40.44	-	D_2O
5α	-	100.97	70.82	72.04	84.41	70.62	33.11	171.11	D_2O
6α	1070	101.84	71.50	72.78	85.04	71.86	26.10	-	DMSO
1β	1576	102.09	72.04	72.28	84.62	71.01	34.43	-	DMSO
2β	1333[c] *1284*	102.03	71.99	72.58	83.18	70.32	51.32	-	DMSO
3β	1128[b]	101.65	71.86	72.40	82.44	68.01	40.47	-	D_2O
4β	1198	102.13	71.86	72.18	85.34	67.03	20.66	118.13	DMSO
5β	-	101.53	71.30	71.88	84.24	70.83	32.83	170.96	D_2O
6β	1247	102.19	72.29	72.54	84.95	72.01	25.98	-	DMSO
1γ	1825[c]	102.02	72.18	72.26	84.05	71.02	34.38	-	DMSO
2γ	1521[c] *1472*	102.03	72.23	72.44	82.65	70.44	51.44	-	DMSO
3γ	1290[b]	100.67	71.86	72.07	81.03	67.78	40.46	-	D_2O
5γ	-	101.75	71.74	71.56	84.09	70.91	32.71	171.00	D_2O
6γ	1426	102.19	72.42	72.51	84.44	72.09	25.89	-	DMSO
7β	1323	97.79	79.42	79.64	79.84	67.76	40.11		D_2O
	other	carbons	60.13	58.21					
8β	1624	99.68	70.51	71.00	79.84	66.76	47.72		D_2O
	other	carbons	51.99	45.26	42.09				
9β	1536[c]	102.55	72.99	73.6	83.05	69.16	50.66		D_2O
	other	carbons	148.12	146.54	145.17	129.72	129.22	50.01	

a. Positive ion detection; Cs^+ ion source. Molecular ion peaks corresponding to the most intense isotopic m/z ratio are reported. Isotope distributions and ratios are compatible with structure assignment. Figures in italics refer to $(M - N_2 + 2H)^+$. b. Free amines used for MS analysis. c. $M+Na^+$ parent ion.

The desired product was isolated in quantitative yield, by precipitation with diethyl ether, filtration, washing with ether and drying under vacuum.

Example 3

General Procedure: Per-6-alkylamino-6-deoxy-cyclodextrins. Per-6-alkylamino-cyclodextrins were synthesized by treating per-6-bromo-6-deoxy-cyclodextrin (compound **1**) with excess of alkylamine (10 molar equivalents amine per Br equivalent) at 80°C for 24 to 48 hours. The reagent/solvent was removed under vacuum and the residue was precipitated in acetone. After filtration, and washing with acetone, the solid was taken up in water and the pH was carefully brought down to 4 with 1M HBr. The aqueous solution was evaporated under vacuum and further dried on the vacuum line. The resulting solid was washed 3 times with hot abs. ethanol in order to remove all of the unreacted starting amine. The last filtrate was perfectly clear. After drying on the vacuum line, persubstitution of the primary face was confirmed by ^{13}C NMR , FAB-MS and elemental analysis.

Per-6-(2-hydroxyethylamino)-6-deoxy-α-cyclodextrin: ^{13}C NMR (D_2O) δ 101.11 (C_1), 82.29 (C_4), 72.30 (C_3), 71.20 (C_2), 67.59 (C_5), 56.47 (CH_2OH), 49.87 (NCH_2), 48.02 (C_6), MS (+FAB) $M+H^{\oplus}$ 1231.3, $M+H_2Br^{\oplus}$ 1313.2. Anal. Calcd for $C_{48}H_{90}N_6O_{30} \cdot 6HBr \cdot 4H_2O$: C, 32.23; H, 5.86; N, 4.70. Found: C, 32.04; H, 5.59; N, 4.55.

Per-6-(2-hydroxyethylamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 101.07 (C_1), 81.91 (C_4), 72.00 (C_3), 71.60 (C_2), 67.47 (C_5), 56.65 (CH_2OH), 49.83 (NCH_2), 48.24 (C_6), MS (+FAB) $M+H^{\oplus}$ 1435.7. A sample for elemental analysis was passed through a column with basic exchange resin (Dowex 1-X8) to afford the free base form of the compound. Anal. Calcd for $C_{56}H_{105}N_7O_{35} \cdot H_2O$: C, 46.24; H, 7.41; N, 6.74; O, 39.6. Found: C, 46.53; H, 7.39; N, 6.63; O, 39.96.

Per-6-(2-hydroxyethylamino)-6-deoxy-γ-cyclodextrin: ^{13}C NMR (D_2O) δ 99.38 (C_1), 79.73 (C_4), 71.88 (C_3), 71.43 (C_2), 67.02 (C_5), 56.55 (CH_2OH), 49.79 (NCH_2), 48.29 (C_6). MS (+FAB) $M+H^{\oplus}$ 1641.7. Anal. Calcd for $C_{64}H_{120}N_8O_{40} \cdot 8HBr \cdot 4H_2O$: C, 32.56; H, 5.81; N, 4.75. Found: C, 32.70; H, 5.56; N, 4.41.

Per-6-(N-methyl-2-hydroxyethylamino)-6-deoxy-α-cyclodextrin: ^{13}C NMR (D_2O) δ 99.21 (C_1), 79.67 (C_4), 71.89 (C_3), 71.55 (C_2), 66.37 (C_5), 56.83 (C6), 55.35 (CH_2OH, CH_2N), 41.55 (CH_3N). MS (+FAB) $M+H^{\oplus}$ 1315.4. Anal. Calcd for $C_{54}H_{112}N_6O_{30} \cdot 6HBr \cdot 2H_2O$: C, 35.31; H, 6.15; N, 4.58. Found: C, 35.26; H, 6.12; N, 4.67.

Per-6-(N-methyl-2-hydroxyethylamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 99.80 (C_1), 80.65 (C_4), 71.70 (C_3, C_2), 66.57 (C_5), 56.85 (C6), 55.25 (CH_2OH, CH_2N), 41.74 (CH_3N). MS (+FAB) $M+H^{\oplus}$ 1534.7, $M+H_2Br^{\oplus}$ 1616.5, $M+H_3Br_2^{\oplus}$ 1696.5. Anal. Calcd for $C_{63}H_{119}N_7O_{35} \cdot 7HBr \cdot 4H_2O$: C, 34.82; H, 6.21; N, 4.51; O, 28.71. Found: C, 34.42; H, 5.98; N, 4.42; O, 27.47.

Per-6-(N-methyl-2-hydroxyethylamino)-6-deoxy-γ-cyclodextrin: ^{13}C NMR (D_2O) δ 100.80 (C_1), 82.27 (C_4), 72.14 (C_3), 71.48 (C_2), 67.18 (C_5), 58.07 (C6), 56.86 (CH_2N), 55.39 (CH_2OH), 42.36 (CH_3N). MS (+FAB) $M+H^{\oplus}$ 1753.5. Anal. Calcd for $C_{72}H_{136}N_8O_{40} \cdot 8HBr \cdot 5H_2O$: C, 34.71; H, 6.23; N, 4.50. Found: C, 34.51; H, 5.91; N, 4.51.

Per-6-(1,3-dihydroxy-2-propylamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 100.94 (C_1), 81.36 (C_4), 71.98 (C_3), 71.52 (C_2), 67.40 (C_5), 60.91 (C_2'), 57.96 (C_1'), 57.22 (C_3'), 45.84 (C_6). MS (+FAB) $M+H^{\oplus}$ 1645.8 found. Anal. Calcd. for $C_{63}H_{119}N_7O_{42} \cdot 7HBr \cdot 3H_2O$: C, 33.38; H, 5.87; N, 4.32. Found: C, 33.39; H, 5.67; N, 4.17.

Per-6-(diethanolamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 99.35 (C_1), 79.81 (C_4), 72.59 (C_2), 71.77 (C_3), 69.89 (C_5), 58.19 (C_2'), 56.53 (C_1'), 55.77 (C_6). MS (+FAB) $M+H^{\oplus}$ 1744.1. Anal. Calcd. for $C_{70}H_{133}N_7O_{42} \cdot 4H_2O$: C, 46.27; H, 7.82; N, 5.40. Found: C, 46.20; H, 7.34; N, 4.96. Calcd. for $C_{70}H_{133}N_7O_{42} \cdot 7HBr \cdot 4H_2O$: C, 35.58; H, 5.46; N, 4.15. Found: C, 35.74; H, 5.98; N, 3.84.

Per-6-(2-methoxyethylamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 100.98 (C_1), 81.84 (C_4), 72.00 (C_3), 71.58 (C_2), 67.35 (C_5), 66.83 (CH_2O), 58.67 (OCH3), 48.57 (NCH_2), 47.79 (C_6). MS (+FAB) $M+H^{\oplus}$ 1534.6, $M+H_2Br^{\oplus}$ 1616.5. Anal. Calcd. for $C_{70}H_{133}N_7O_{42} \cdot 7HBr \cdot 4H_2O$: C, 34.82; H, 6.22; N, 4.51. Found: C, 34.92; H, 6.12; N, 4.51.

Example 4

General Procedure: Per-6-(N,N-dimethyl-2-aminoethylamino)-6-deoxy-cyclodextrins. Per-6-(N,N-dimethylethylenediamino)-β-cyclodextrins were synthesized by treating **1** with excess of ethylenediamine (10 molar equivalents amine per Br equivalent) at 80°C for 12 hours. The reagent/solvent was removed under vacuum and the residue was precipitated in acetone. After filtration, and washing with acetone, the solid was taken up in water and treated with Amberlite IRA-410 ion exchange resin in the hydroxide form. The initial chloride commercial form of the resin was changed into the hydroxide form prior to use by washings with 20 volumes of 1M NaOH followed by rinsing with 4 volumes of water. The resin load was calculated based on a ratio of 3.4 meq. anion/g wet resin and the amount used was twice the calculated one. The exchange was performed by stirring the resin beads with the diluted aqueous solution of crude CD for 2 hours at r.t. Filtration and washing of the resin with water afforded a clear filtrate that was rotavapped and dried. The solid residue was thoroughly washed with acetone to yield the pure CD-ethylenediamino-derivatives in their free base form.

Per-6-(N,N-dimethyl-2-aminoethylamino)-6-deoxy-α-cyclodextrin: ^{13}C NMR (D_2O) δ 101.66 (C_1), 82.66 (C_4), 73.07 (C_3), 72.02 (C_2), 70.45 (C_5), 57.61 (C_2'), 49.19 (C_1'), 46.74 (C6), 44.53 ($2 \cdot CH_3$). MS (+FAB) $M+H^{\oplus}$ 1625. Anal. Calcd. for $C_{70}H_{140}N_{14}O_{28} \cdot 3H_2O$: C, 50.05; H, 8.76; N, 11.67. Found: C, 49.99; H, 8.11; N, 11.50.

Per-6-(N,N,N'-trimethyl-2-aminoethylamino)-6-deoxy-β-cyclodextrin: ^{13}C NMR (D_2O) δ 100.66 (C1), 81.97 (C4), 73.13 (C3), 71.98 (C2), 69.59 (C5), 57.59 (C_2'), 55.60 (C_2'), 55.41 (C_6), 44.60 (CH_3), 42.47 (2 · CH_3). MS (+FAB) M+H$^{\oplus}$ 1723.4. Anal. Calcd. for $C_{77}H_{154}N_{14}O_{28}$ · $7H_2O$: C, 49.98; H, 9.15; N, 10.60. Found: C, 50.50; H, 8.22; N, 9.81.

Per-6-imidazolyl-6-deoxy-β-cyclodextrin. A mixture of **1β** (0.3152g, 0.0002 mole) and imidazole (0.272g, 0.004 mole) in a minimum amount of anhydrous DMF (0.3 ml) was stirred at 75-80∘C for 24 hours. The reaction mixture was poured in 30 ml of H_2O with vigorous stirring. The resulting white precipitate was filtered and then taken in 20 ml of H_2O. 1M HBr was added slowly to the suspension until the pH of the resulting solution dropped down to 3. The aqueous solution was rotary evaporated and then further dried on the vacuum line. The resulting solid was washed 3 times with hot abs. ethanol in order to remove all of the unreacted imidazole. Removal of the ethanol traces from the final compound was achieved by succesive additions and evaporations of MeOH under vacuum, followed by vacuum drying to yield the desired product · 7HBr salt (0.3g, 73%) as a white powder. ^{13}C NMR (D_2O) δ 136.24 (+, C_2'), 123.2 (-, C_4'), 120.65 (-, C_5'), 101.97 (-, C_1), 82.36 (-, C_4), 72.14 (-, C_3), 71.68 (-, C_2), 69.49 (-, C_5), 49.61 (+, C6). MS (+FAB) M+H$^{\oplus}$ 1485.1.

Per-6-tyramino-6-deoxy-β-cyclodextrin. Over a suspension of 3.84g tyramine (0.028mole) in 12 ml of dry DMF at 70°C was added in portions 3.152g β-CD-Br (**1β**, 0.002 mole). One hour after the addition was completed the reaction mixture cleared and started to darken. The solution was stirred overnight at 75-80°C to allow completion of the substitution. Evaporation of DMF, followed by precipitation in acetone afforded a light-brown powder. The aqueous solution of the crude product was titrated with 1M HBr to pH 3 and then rotavapped. The remaining residue was refluxed 3 times in abs. ethanol (or until the filtrate was clear) with alternative filtrations. The resulting solid was rotavapped 2 more times with methanol in order to remove the ethanol traces to yield the desired product · 7HBr as a white powder. ^{13}C NMR (D_2O) δ 154.54 (*ipso* C-OH), 129.88 (arom.-CH), 127.38 (*ipso*-C), 115.57 (arom. CH), 101.26 (C_1), 82.40 (C_4), 72.12 (C_3), 71.59 (C_2), 67.67 (C_5), 49.78 (CH_2N), 48.73 (C_6), 31.00 (CH_2-phenol). MS (+FAB) M+H$^{\oplus}$ 1967.5. Anal. Calcd. for $C_{98}H_{133}N_7O_{35}$ · 7HBr · $10H_2O$: C, 43.34; H, 5.97; N, 3.61. Found: C, 43.01; H, 5.62; N, 3.80.

Per-6-benzylamino-6-deoxy-β-cyclodextrin. See the General procedure for Per-6-alkylamino-6-deoxy-cyclodextrin. ^{13}C NMR (D_2O) δ 130.49 (*ipso*-C), 130.34 (2 arom CH), 129.64 (1 arom CH), 129.01 (2 arom CH), 101.38 (C_1), 82.70 (C_4), 72.00 (C_3), 71.61 (C_2), 67.51 (C_5), 51.83 (benzyl CH_2), 48.77 (C_6). MS (+FAB) M+H$^{\oplus}$ 1757.9.

Example 5

General procedure for per-6-cyano-6-deoxy-CD. The per-6-cyanoCD was formed from reaction of per-bromoCD (**1**) with KCN (1.3n eq.; n=6,7,8) in DMF with heating at 80°C

for 24 hours. After evaporation of solvent, water was added, yielding an off-white precipitate which was filtered. Thorough washing with water and methanol was responsible for isolation of the nitrile product in 65-70% yield.

Per-6-cyano-6-deoxy-α-cyclodextrin. ^{13}C NMR (DMSO-*d6*) δ 118.35 (CN), 101.94 (C_1), 85.84 (C_4), 72.44 (C_3), 71.65 (C_2), 66.85 (C_5), 20.93 (C_6)

Per-6-cyano-6-deoxy-β-cyclodextrin. ^{13}C NMR (DMSO-*d6*) δ 118.08 (CN), 102.11 (C_1), 85.32 (C_4), 72.16 (C_3), 71.84 (C_2), 67.01 (C_5), 20.64 (C_6)

Per-6-cyano-6-deoxy-γ-cyclodextrin. ^{13}C NMR (DMSO-*d6*) δ 118.11 (CN), 102.18 (C_1), 84.85 (C_4), 72.11 (C_3), 72.04 (C_2), 67.08 (C_5), 20.58 (C_6)

General procedure for per-6-aminomethyl-6-deoxy-CD from per-6-cyano-6-deoxy-CD. The per-6-cyano-6-deoxy-CD (0.2mmole) was hydrogenated in a Parr-pressure hydrogenator under a 50-55 psi H_2 pressure, at room temperature. The nitrile was taken in water (60ml) and then, the catalyst (n · 0.2 · 125mg PtO_2; n=6,7,8) and the 1M HCl (n · 0.2mmoles; n=6,7,8) were added to the suspension. PtO_2 was used without prehydrogenation. After only 3 hours of hydrogenation the reaction mixture was clear and the reduction was stopped. Filtration of the catalyst suspension through a water pre-washed Celite bed followed by evaporation of the aqueous solution afforded the desired product · 7HCl as a white solid.

Per-6-aminomethyl-6-deoxy-α-cyclodextrin. ^{13}C NMR (D_2O) δ 101.30 (C_1), 84.00 (C_4), 73.11 (C_3), 71.63 (C_2), 69.77 (C_5), 36.05 (C_7), 27.67 (C_6). MS (+FAB) $M+H^{\oplus}$ 1051.2.

Per-6-aminomethyl-6-deoxy-β-cyclodextrin. ^{13}C NMR (D_2O) δ 101.33 (C_1), 83.51 (C_4), 72.70 (C_3), 71.90 (C_2), 69.83 (C_5), 36.20 (C_7), 27.72 (C_6). MS (+FAB) $M+H^{\oplus}$ 1226.4.

Per-6-aminomethyl-6-deoxy-γ-cyclodextrin. ^{13}C NMR (D_2O) δ 100.83 (C_1), 82.62 (C_4), 72.54 (C_3), 72.12 (C_2), 69.82 (C_5), 36.40 (C_7), 27.89 (C_6). MS (+FAB) $M+H^{\oplus}$ 1401.7.

Sulfopropylation of per-6-aminomethyl-6-deoxy-β-cyclodextrin To 50mg of per-6-aminomethyl-6-deoxy-β-cyclodextrin in H_2O (0.6ml) was added molten propyl sultone (0.06ml) using a pre-warmed syringe. The reaction mixture was stirred for 2 hours at r.t. Acetone was added and the precipitate filtered. The precipitate was taken up in a minimum vol. of water and selectively precipitated with ethanol. The resulting white powder was washed with refluxing ethanol, to yield the desired prduct: ^{13}C NMR (D_2O) δ 101.53 (C_1), 84.21 (C_4), 72.87 (C_3), 72.00 (C_2), 69.96 (C_5), 36.47 (C_7), 27.99 (C_6), 38.07 (C_8), 22.57 (C_9), 49.17 (C_{10}).

Compounds prepared in accordance with the above protocols have been evaluated for their role in adhesion and/or inhibition of neurite extension by nerve growth factor (NGF)-responsive cells.

It has been previously demonstrated that heparin sulfate proteoglycans (HSPG) of

neuronal origin have neurite promoting activity either when complexed to the neuronal cell surface, or as immobilized substrates. It has also been demonstrated that the neurite growth promoting properties of neuronal HSPG's involve the complex carbohydrate side chains known as glycosaminoglycans, and that the degree of sulfation of these GAG's is critical to their neurite promoting activities.

In the spinal cord of embryo chick, during the window of permissiveness for regenerative growth, the milieu encountered by descending axons of brainstem neurons has a high HS/CS ratio, and neurite-promoting HSPG's in extracts of spinal cord are present in high titre. Alternatively, the milieu encountered by regenerating axons during the non-permissive period for axonal regrowth in the chick embryo spinal cord is enriched for chondroitin sulfate proteoglycans (CSPG's), and blockade of the effects of CSPG from extracts of spinal cord from the non-permissive period uncovers a permissive milieu for neurite growth. These observations add to a growing literature on the relative growth inhibitory effects of the CSPG's during development and regeneration of the nervous system.

Proteoglycans complexed to the neuronal cell surface or immobilized within the extra- neuronal environment interact via sulfate or carboxylate groups with glycosaminoglycan binding domains of the extracellular space that are found as specific domains within known adhesion proteins. While the primary amino acid sequences of such domains are heterogeneous, they share a consensus structure comprised of basic and hydrophobic/non-polar epitope repeats.

To mimic such structures so as to develop small molecule modulators of PG-mediated neuronal adhesion and neurite growth, the CD derivatives described above have been used in assays of neuronal adhesion and neurite growth, and compared with known complex carbohydrates to elucidate the glycosaminoglycan (GAG) specificity of their effects.

MATERIALS AND METHODS

Substrate preparation

The wells of the plastic tissue culture plates are treated by incubating them overnight at 37C with 5μl (Terasaki plates) or 30μl (96 well) of sterile aqueous solution of the SPA-βCDs or PDL.

Before seeding the cells, the plates are washed twice with sterile distilled water and rinsed once with serum-free medium.

Cell culture

PC12 (rat pheochromocytoma) cells were obtained from ATCC and maintained in polystyrene culture dishes (Corning) in RPMI (Gibco) containing 10% heat inactivated donor

horse serum and 5% fetal calf serum (Wisent). Cells were subcultured weekly at approximately 1:8. Cells were not used beyond 25 passages from ATCC stock and were revived from frozen stock when required. "Primed" PC12 cells were exposed to 50ng/ml NGF (Cedarlane) in serum containing medium for 5 days before use.

Acid phosphatase assay for cell adhesion

Adhesion is evaluated by a colorimetric assay which measures the lysosomal acid phosphatase to determine cell number (Connolly et al., 1986) modified by Ueda et al. (1994) for use with cultured neuronal cells.

PC12 cells are seeded in serum-free medium in treated wells of a 96 well plate, (6000-9000 cells per well) and allowed to adhere at 4°C for 60 minutes. The medium is then removed and the wells are washed gently with 100μl of PBS. 100μl of assay buffer (0.1M sodium acetate pH 5.5, 0.1% Triton X-100 and 10mM p-nitrophenyl phosphate - Sigma 104 substrate) is added to each well. Plates are incubated at 37°C for 2 hours. The reaction is stopped by the addition of 10μl of 1M sodium hydroxide and the color development measured at 405nm in a Titertek microplate reader.

Assay of neurite growth

Dissociated cells enriched for sensory neurons from DRG of ED8 chick were prepared as described in detail previously (Sutter et. al., 1979). Cells were seeded into the treated wells of Terasaki plates at a density of 900-1200 cells per well in supplemented Ham's F12 medium with 5% fetal calf serum and NGF at a final concentration of 1ng/ml. The cells are incubated at 37°C, 5% CO_2 overnight. The wells are scored blind at 18-22 hours for neurite growth by counting all cells on the lower horizontal surface of the wells, which is approximately 15% of the surface area of the top of the tapered wells. Each experiment includes quadruplicate determinations for each treatment.

When the derivatized cyclodextrins were added to the neurons at the time of seeding in Terasaki wells, they exhibited inhibitory activity towards NGF-mediated neurite growth.

The tetradecasulfated β-cyclodextrin was the most potent inhibitor. Of the amine-derivatized β-cyclodextrins, "H" appeared to be the least inhibitory. The parent, underivatized β-cyclodextrin, did not affect neurite extension by the cells, and at the concentration tested, the free amines "G", "H" and "I" (250μM) did not substantially reduce the percentage of cells that were neurite bearing. However, the effect on overall viability by the free amines at this concentration requires further investigation.

Cyclodextrins as templates for neurite growth

I. With NGF alone

When incubated on the polystyrene wells overnight at 37°C, 4 of the 6 derivatized cyclodextrins were found to interact with the plastic surface in a manner that permitted the

DRG neurons to disperse and extend neurites in response to NGF, in a fashion similar to that seen with poly-D-lysine treatment of the Terasaki wells.

The cyclodextrins were dissolved in water at a nominal concentration of 10mg/ml and filter sterilized. 5μl of the solution was aliquoted into wells of Terasaki plates and the plates incubated in a CO_2, humidified incubator overnight. Prior to seeding the cells, the wells are washed twice with sterile water and rinsed with culture medium. When cultured on plastic (treated with water), the cells do not disperse evenly on the available surface. The phase bright cells cluster and the result is sparse clumps of rounded cells atop neurite bearing cells. Conversely, when poly-D-lysine is used as a substrate, the cells disperse uniformly at the bottom of the well with individual cells clearly defined.

Four of the amine-derivatized β-cyclodextrins could serve as a substrate for neurite growth, with cells morphology and extent of neurite growth similar to that seen with poly-D-lysine as a substrate. The growth response on wells treated with cyclodextrin "h" did not differ from that on the plastic surface, and the sulfated cyclodextrin did not permit neurite growth above blank levels (no NGF).

Wells treated with 5mM aqueous solutions of the free amines "G", "H" and "I" did not exhibit a response different from plastic alone (data not shown).

ii. Effects of mixed sulfated glycosaminoglycans in solution

Preliminary experiments were carried out with poly-D-lysine or the amine-cyclodextrins as substrate. DAG neurons were seeded in the presence of 1ng/ml NGF and co-incubated with 10μg/ml chondroitin sulfate or heparan sulfate, with the following results:

Adhesion

Adhesion was assessed by assaying for acid phosphatase released by cells remaining in treated wells. The values obtained were compared to control adhesion of cells on plastic treated with water.

Table 1

	8 day chick DAG	PC 12 naive	PC12 NGF-primed 7 days
pdl (0.1mg/ml)	+	+	+
14βSO$_4$CD (10mg/ml)	-	-	-
parent βCD (5 mg/ml)*		-	-
"E" βCD (10mg/ml)		+	+
"F" βCD (10mg/ml)		+	+
"G" βCD (1mg/ml)**	+	+	+
"H" βCD (10mg/ml)	-	-	-
"E" free (amine (5mM)		-	-
"F" free amine (5mM)		-	-
"G" free amine (5mM)		-	-

- no different from value obtained on untreated plastic
\+ greater than value obtained on plastic (p>.05 t-test)
* the parent β cyclodextrin was not soluble in water at 10mg/ml
** 1mg/ml nominal concentration of cyclodextrin "G" was as effective as 10mg/ml.

% OF ITS CONTROL (NO ADDITIVE)

ADDITIVE:

SUBSTRATE	CHONDROITIN SULFATE	HEPARAN SULFATE
"E"	93	59
"F"	112	81
"G"	111	50
"H"	250	151
"I"	114	33
pdl	141	93

Amine pendant groups designated by capital letters:
"E" - $CH_3NHCH_2CH_2NH_2$
"F" - $H_2NCH_2CH_2NHCH_2CH_2NH_2$
"G" - $HN(CH_2CH_2NHCH_2CH_2NH_2)_2$
"H" - $(CH_3CH_2)_2NCH_2CH_2NH_2$
"I" - $(CH_3)_2NCH_2CH_2NH_2$

A Leitz Diavert inverted microscope equipped with phase optics was used to score

neurite growth. A neurite was scored as such if its calibre from origin to terminal was approximately the same and the length was equal to or greater than 1.5 cell body diameters. Data expresses neurite bearing cells as a percent of total viable cells on the lower surface.

Statistical analysis

Data was analysed using Sigma Stat version 1.01 (Jandel Scientific) by one way anova (α=0.05) with Student-Neuman-Keuls or Dunnetts-t post test.

1. Soluble polyammonium - β cyclodextrins (SPA-BCD's) block NGF-mediated neurite growth on poly-D-lysine.

In the presence of NGF primary sensory neurons extend processes on a poly-D-lysine substrate. At 18-22 hours four SPA-BCD's inhibited neurite growth in a concentration dependent fashion (Figure 1). At 500 μg/ml the rank ordering of inhibition of neurite growth was E>G>K>H. A positive control for these studies was BCD-14S, a putative GAG mimic, which at a concentration of 200μg/ml blocked neurite growth by 94% (data not shown). Free SPA's and underivatized BCD's did not influence neurite growth. Free E SPA reduced viability of neurons to about 21% of control, while survival in the presence of all other free amines was on average 74% of control.

2. SPA-BCD's do not alter neuronal adhesion to poly-D-lysine.

The influence of SPA-BCD's on neuronal adhesion to PDL was carried out using naive PC12 cells. Adhesion to PDL was significantly greater (p=.009) than to plastic alone. However, neither underivatized BCD nor any of the SPA-BCD's had any significant influence on adhesion (Table 1I).

Table II

EFFECTS OF COMPOUNDS ON ADHESION TO POLY-D-LYSINE

Substrate	Treatment	Adhesion*
plastic	0	69+11&
PDL	0	100+24
PDL	5mM Tris	90+76
PDL	parent BCD	79+13
PDL	G-BCD/Tris	87+16
PDL	G free	93+18
PDL	G-BCD	104+20
PDL	H-BCD	106+13

& - significant difference vs PDL

3. SPA-BCD's as substrates.

Adhesion: None of the free amines including PAMAM, or parent BCD had effects on adhesion of PC-12 cells or DRG neurons that differed significantly from the tissue culture

plastic substrate. The dose response profile for adhesion of PC-12 cells and DRG neurons by G-BCD was significantly greater than that to plastic, and was saturated at a coating concentration of 0.1mg/ml. (Figure 2). For E-BCD significant adhesion for both PC-12 cells and DRG neurons occurred only at a coating concentration of 10mg/ml. There were no obvious effects of H- and K-BCD's on adhesion of either PC-12 cells or DRG neurons at coating concentrations of 10mg/ml.

Neurite Growth: None of the free amines used to derivatize BCD or the parent BCD had any influence on NGF-mediated neurite growth on a tissue culture plastic substrate. The dose response profile for coating of plastic to support neurite growth by G-BCD demonstrated saturation at 5mg/ml coating concentration (Fig.3). At a coating concentration of 10mg/ml, E-BCD supported the same level of neurite growth as PDL used at 0.1 mg/ml. At 10mg/ml K-BCD supported approximately 50% of the neurite growth as observed on PDL, and neurite growth supported by H-BCD when used at 10mg/ml to treat the culture surface was no different than that observed on plastic alone. The starburst amine PAMAM used at 10mg/ml to coat the substrate was as effective as K-BCD at the same concentration.

Neuronal morphology: Generally, on tissue culture plastic and on the less favourable substrates for adhesion, cell adhesion to surfaces was uneven, and was characterized by a tendency for the cells to clump. Neurites appeared to fasciculate and bridged between the cell aggregates. More even cell dispersal was a feature of PDL and substrates that supported adhesion and neurite growth, and neurites appeared not to fasciculate.

5. Selectivity of substrates of adhesion and growth for glycosaminoglycans: To determine the GAG selectivity of the substrates, G-BCD was chosen as the compound that gave the highest signal-to-noise ratio in adhesion and neurite growth assays, and its properties were compared to those of PDL. Heparin and CS-GAG's were used at concentrations of 10μg/ml which have been shown previously to distinguish between the effects of HSPG's and CSPG's on a HSPG-selective substrate. As depicted in Table III, on a PDL substrate, cell surface CSPG's were involved in adhesion but not neurite growth, while HS-GAG's were involved in both adhesion and neurite growth. These observations, combined with analyses on binding of PG's to PDL indicate that PDL does not provide a GAG-selective substrate. On the G-BCD substrate however, cell surface CSPG was not involved in either adhesion or neurite growth, whereas cell surface HSPG's contributed to both of these functions. Thus for neurons, the G-BCD compound was HSPG-selective (Table III).

Table III
SELECTIVITY OF SUBSTRATES FOR GLYCOSAMINOGLYCANS

ADDITIVE	% OF CONTROL			
	NEURITE GROWTH ON		ADHESION ON	
	PDL	G-BCD	PDL	G-BCD
CS-GAG's	109+20	89+22	76+3	99+7
Heparin	68+13	47+4	51+6	43+7

The principal observation of these studies is that small molecule compounds comprised of soluble polyammonium species coupled covalently to BCD's act as inhibitors of neurite growth on PDL, in part by interfering with the interaction of cell surface HSPG's with this substrate.

On a PDL substrate neuronal cell surface CSPG's and HSPG's were involved in adhesion, but only HSPG was involved in neurite growth. The observation that the SPA-BCD's interfered with neurite growth on PDL with no influence on adhesion suggest that they are HS selective. Such proof was forthcoming for G-BCD which was shown to be a HS selective substrate for neurite growth (and for adhesion).

The finding that HSPG's are involved in neurite growth both on PDL and on G-BCD is consistent with observations that HSPG's are preferentially off-loaded distally from the anterograde axonal transport pool relative to CSPG's, and that HSPG's are less avidly bound to PDL than CSPG's. In other words, HSPG's appear to be in a spatially preferable position within the growth cone to mediate neurite growth, and have (relative to CSPG's) low affinity interactions with PDL that would be required for the dissociation of neurite contact with the substrate of growth necessary for process elongation.

The nature of the GAG-mediated interactions with binding domains in the extra-neuronal milieu that mediate neurite growth have begun to be elucidated in the present studies. A review of published literature on binding motifs within adhesion molecules for GAG's indicates that basic charge is more dense and more uniform in sub-domains of motifs that display CS selectivity. For HS-selective motifs, basic charge density in sub-domains is less because charged residues are separated by longer stretches of more hydrophobic residues (Table IV). To the extent that we have generated compounds that are HS selective, the SPA-BCD's closely mimic HS binding motifs on CAM's.

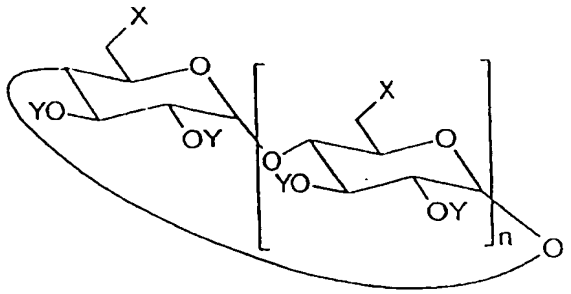
The synthesis of HS selective small molecule compounds that block neurite growth have implications for CNS disorders where aberrant neurite growth is a disease phenotype, and where HSPG's are implicated. For example, in Alzheimer's disease, synapse loss,

aberrant (dystrophic) neurite growth, and neurofibrillary tangle formation are strong correlates of disease severity. HSPG's are molecular constituents of dystrophic neurites and of NFT's. To the extent that dystrophic neurite formation is a disease severity correlate in AD, small molecule HS-selective antagonists of neurite growth may have therapeutic potential.

As will be appreciated for in-vivo administration to a patient in need thereof, the CDs of the present invention may be administered by intravenous injection, intracerebro-ventricular injection, in a pharmaceutically and physiologically acceptable carrier therefor, such as water, isotonic saline, or encapsulated in a liposome or the like. It will also be appreciated that nerve growth inhibition is important in the treatment and management of epilespy, amyloid diseases such as Alzheimers, and chronic pain syndrome. Nerve growth stimulation is important in the treatment of spinal cord injuries, peripheral nerve injuries, diabetes, chemotherapy exposure and stroke among others.

WE CLAIM:

1. A process for producing homogeneous cyclodextrin derivatives of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium; comprising reacting a cyclodextrin as defined above but bearing free hydroxyl groups at the carbon-6 position with a compound of the formula:

$$R''_2\,NCH\,X'^{*}\,X''^{-}$$

where R″ is an alkyl containing 1-5 carbon atoms; and X′ is a halogen selected from the group consisting of bromine and iodine, so as to produce a halogenated derivative, and converting said halogenated derivative to a selected said homogeneous cyclodextrin derivative by substitution or exchange of said X′ at carbon 6.

2. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal sulfite salt under pressure so as to produce a homogeneous cyclodextrin derivative having a sulfonyl group at each primary face carbon-6 position.

3. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal azide salt and reduced to yield a homogeneous derivative having an

amino group at each primary face carbon-6 position.

4. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal cyanide salt and reduced to yield homogeneous amino derivative having an aminomethylene group at each primary face carbon-6 position.

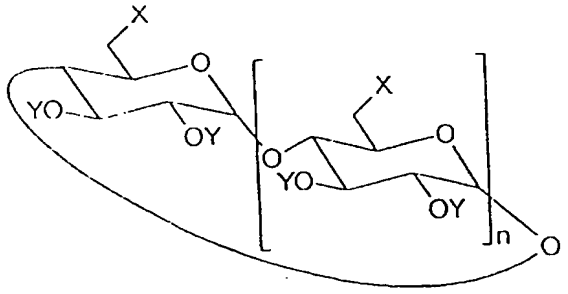
5. A process as claimed in claim 1 wherein said halogenated derivative is reacted with thiourea so as to produce a thiouronium derivative having a thiouronium group at each primary face carbon-6 position. Thiouronium derivative is hydrolysed or alcoholized so as to produce a homogeneous mercapto derivative having a mercapto or thiol group at each primary face carbon-6 position.

6. A process as claimed in claim 5 wherein said mercapto derivative is reacted with an alkyl halide so as to produce a homogeneous mercaptoamine derivative having a sulfide functionality at each primary face carbon-6 position.

7. A process as claimed in claim 1 wherein said halogenated derivative is reacted with an amine so as to produce a homogeneous derivative having an amine functionality at each primary face carbon-6 position.

8. A process as claimed in claim 3 wherein said amino derivative is reacted with an aldehyde so as to produce a homogeneous mercapto derivative having a mercapto or thiol group at each primary face carbon-6 position.

9. A homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium.

10. A homogeneous amino cyclodextrin derivative as claimed in claim 9 derivatized with an amino selected from the group consisting of

$CH_3NHCH_2CH_2NH_2$

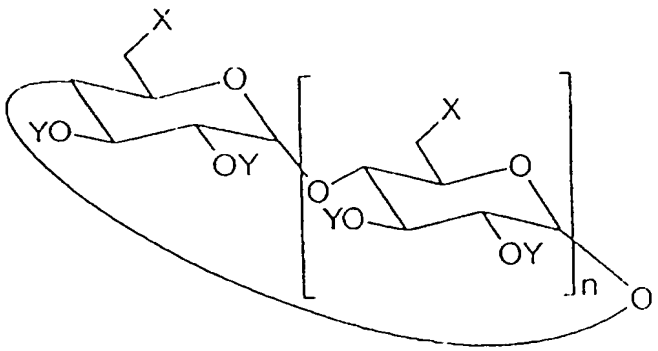
$H_2NCH_2CH_2NHCH_2CH_2CH_2$

$HN(CH_2CH_2NHCH_2CH_2NH_2)_2$

$(CH_3CH_2)_2NCH_2CH_2NH_2$ and $(CH_3)_2NCH_2CH_2NH_2$.

$NH_2CH_2\ C_5H_4N$.

11. A method for modulating nerve process growth comprising administering to a patient in need thereof a homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium in admixture with a pharmaceutically acceptable.

12. A method as claimed in claim 11 wherein said modulating step comprises inhibition.

13. A method as claimed in claim 11 wherein said modulating step comprises neurite growth.

14. A method as claimed in claim 11 wherein said homogeneous cyclodextrin derivative is an amino cyclodextrin derivatized with an amine selected from the group consisting of

$CH_3NHCH_2CH_2NH_2$

$H_2NCH_2CH_2NHCH_2CH_2CH_2$

$HN(CH_2CH_2NHCH_2CH_2NH_2)_2$

$(CH_3CH_2)_2NCH_2CH_2NH_2$ and $(CH_3)_2NCH_2CH_2NH_2$

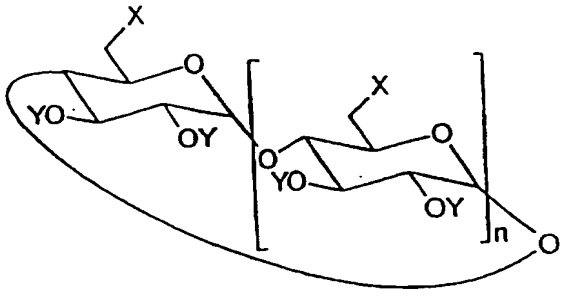
$NH_2CH_2C_5H_4N$

or a salt thereof.

AMENDED CLAIMS

[received by the International Bureau on 1 December 1997 (01.12.97) original claims 8-14 amended; remaining claims unchanged (4 pages)]

1. A process for producing homogeneous cyclodextrin derivatives of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;

Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium; comprising reacting a cyclodextrin as defined above but bearing free hydroxyl groups at the carbon-6 position with a compound of the formula:

$$R''_2\,NCH\,X'^{+}\,X'^{-}$$

where R" is an alkyl containing 1-5 carbon atoms; and X' is a halogen selected from the group consisting of bromine and iodine, so as to produce a halogenated derivative, and converting said halogenated derivative to a selected said homogeneous cyclodextrin derivative by substitution or exchange of said X' at carbon 6.

2. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal sulfite salt under pressure so as to produce a homogeneous cyclodextrin derivative having a sulfonyl group at each primary face carbon-6 position.

3. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal azide salt and reduced to yield a homogeneous derivative having an

amino group at each primary face carbon-6 position.

4. A process as claimed in claim 1 in which said halogenated derivative is reacted with an alkali metal cyanide salt and reduced to yield homogeneous amino derivative having an aminomethylene group at each primary face carbon-6 position.

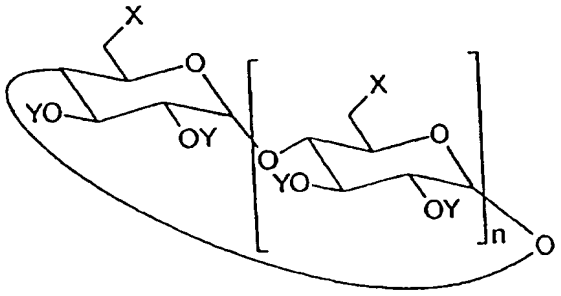
5. A process as claimed in claim 1 wherein said halogenated derivative is reacted with thiourea so as to produce a thiouronium derivative having a thiouronium group at each primary face carbon-6 position. Thiouronium derivative is hydrolysed or alcoholized so as to produce a homogeneous mercapto derivative having a mercapto or thiol group at each primary face carbon-6 position.

6. A process as claimed in claim 5 wherein said mercapto derivative is reacted with an alkyl halide so as to produce a homogeneous mercaptoamine derivative having a sulfide functionality at each primary face carbon-6 position.

7. A process as claimed in claim 1 wherein said halogenated derivative is reacted with an amine so as to produce a homogeneous derivative having an amine functionality at each primary face carbon-6 position.

8. A process as claimed in claim 3 wherein said amino derivative is reacted with an aldehyde and reduced so as to produce a homogeneous amino derivative having an amino group at each primary face carbon-6 position.

9. A homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 5 to 12;

X is selected from the group consisting of NH_2RQ, NHR_2Q, NR_3Q, $NHRR'Q$, $NRR'R^2Q$, $NR_2R'Q$, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, $CH_2NHRR'Q$, $CH_2NRR'R^2Q$, $CH_2NR_2R'Q$, and SR;

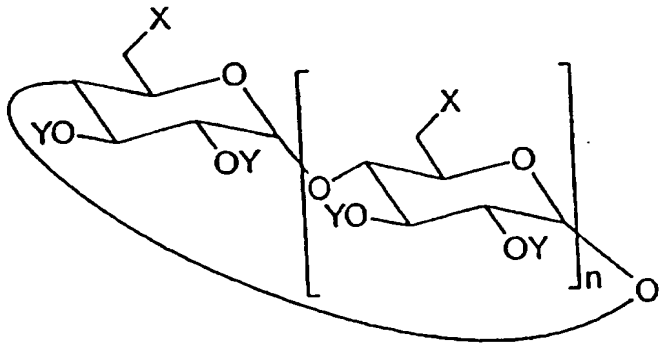
Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;

where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10 counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

with the proviso that when X=NH_2RQ or NHR_2Q that R is not an unbranched alkyl chain, nor an unbranched alkyl chain bearing one hydroxyl group;
and with the proviso that X is not selected from a piperidine, N-methyl piperazine, adenine, imidazole, histamine, mercaptomethyl imidazole, pyridoxamine, thiourea;
and with the proviso that when X=SR , that R is not a C1-C10 benzene derivative nor aminoethyl.
Q is an anionic counterion; and
Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium.

10. A homogeneous amino cyclodextrin derivative as claimed in claim 9 derivatized with an amino where X is selected from the group consisting of
$NHCH_2CH_2NH_2$
$HNCH_2CH_2NHCH_2CH_2NH_2$
$HNCH(CH_2OH)_2$
$(R^4)_2NCH_2CH_2NH$, (R^4 = Me, Et)
$NH_2CH_2C_5H_4N$,
or salts thereof.

11. A method for modulating nerve process growth comprising administering to a patient in need thereof a homogeneous cyclodextrin derivative of the formula



(I)

in which n is an integer from 5 to 12;
X is selected from the group consisting of NH_2, NH_3Q, NH_2RQ, NHR_2Q, NR_3Q, $NHRR^1Q$, NRR^1R^2Q, NR_2R^1Q, CH_2NH_2, CH_2NH_3Q, CH_2NH_2RQ, CH_2NHR_2Q, CH_2NR_3Q, CH_2NHRR^1Q, $CH_2NRR^1R^2Q$, $CH_2NR_2R^1Q$, SR^3 and $SO_3^-Z^+$;
Y is selected from H, alkyl or carboxyl ester chains containing from 1-20 carbon atoms which may contain nitrogen and unsaturations;
where R, R^1 and R^2 are the same or different containing 1-20 carbon atoms, 1-10 nitrogen atoms, 1-4 oxygen atoms, and 4-80 hydrogen atoms, and with 1-10

counterions, and including groups in which C,H and N are present in a heterocyclic ring; or $C_3H_6SO_3Z$;

R^3 is H or R;

Q is an anionic counterion; and

Z is a cation selected from the group consisting of proton, sodium potassium or trialkylammonium in admixture with a pharmaceutically acceptable carrier thereof.

12. A method as claimed in claim 11 wherein said modulating step comprises inhibition.

13. A method as claimed in claim 11 wherein said modulating step comprises neurite growth.

14. A method as claimed in claim 11 wherein said homogeneous cyclodextrin derivative is an amino cyclodextrin derivatized with an amine selected from the group consisting of

$NHCH_2CH_2NH_2$

$HNCH_2CH_2NHCH_2CH_2NH_2$

$HNCH(CH_2OH)_2$

$(R^4)_2NCH_2CH_2NH_2$, (R^4=Me, Et)

$NH_2CH_2C_5H_4N$

or salts thereof.

INHIBITION OF NEURITE GROWTH BY SPAβCD IN SOLUTION

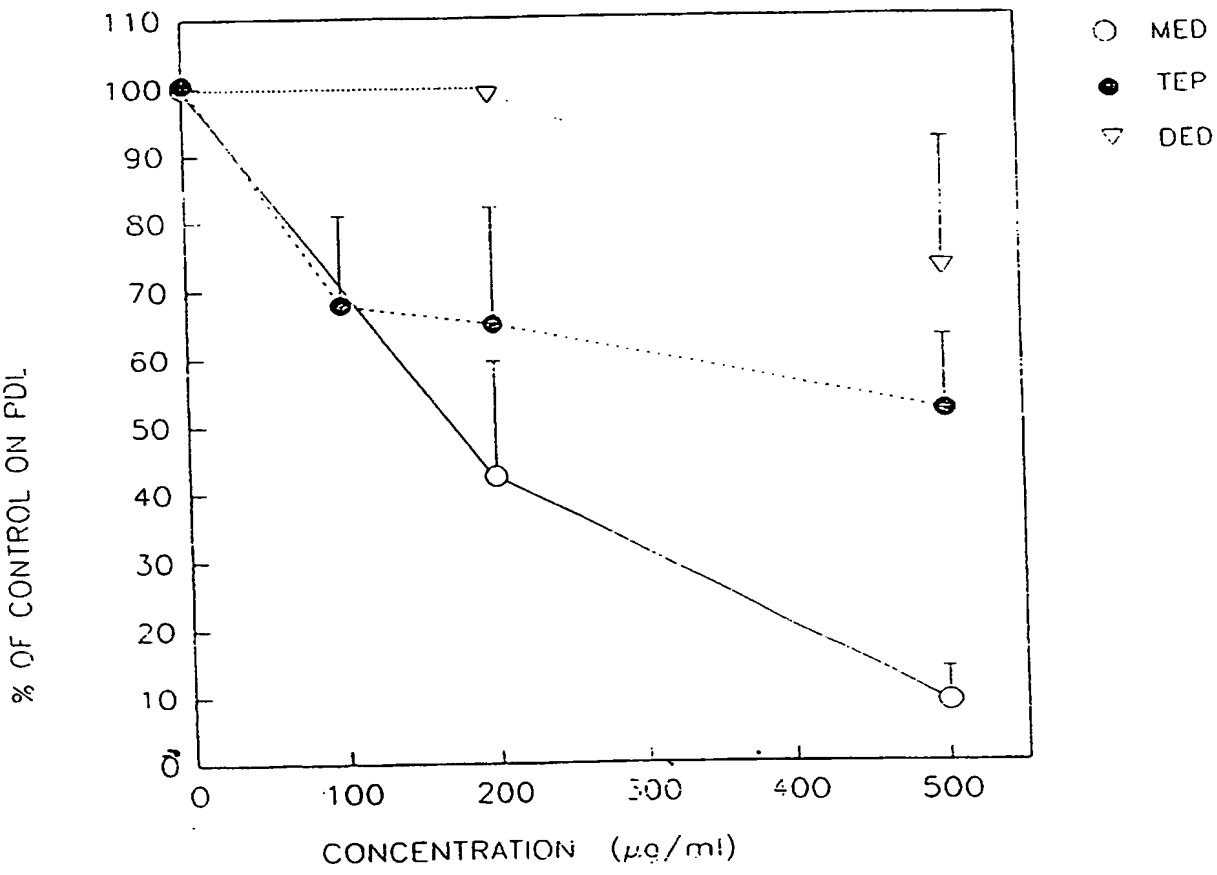


FIGURE 1

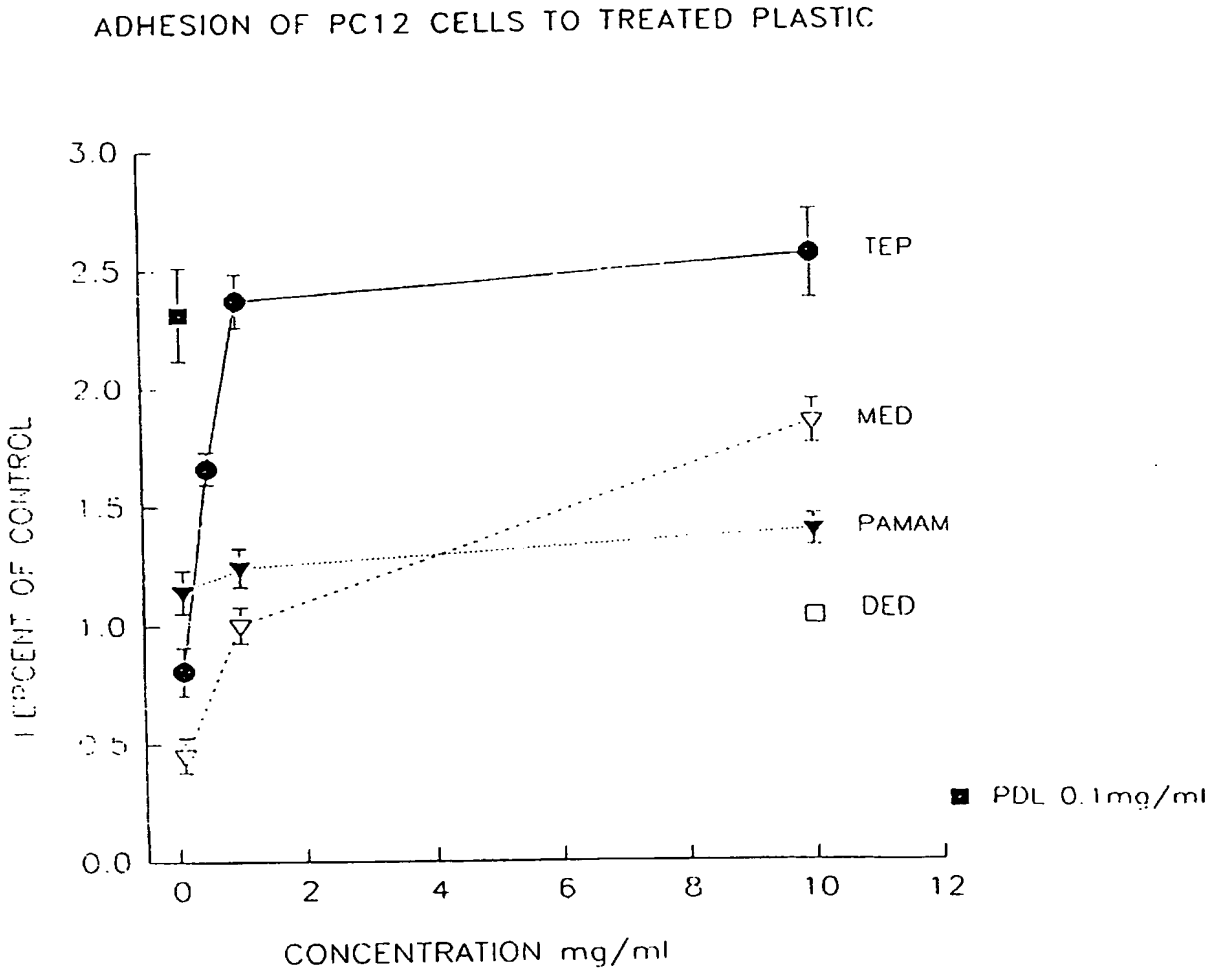

ADHESION OF PC12 CELLS TO TREATED PLASTIC
3.0
2.5
2.0
1.5
1.0
0.0
0
2
4
6
8
10
12
CONCENTRATION mg/ml
TEP
MED
PAMAM
DED
PDL 0.1mg/ml

FIGURE 2

SUPPORT OF NEURITE GROWTH BY ED8 DRG NEURONS ON IMMOBILIZED SPAβCDs

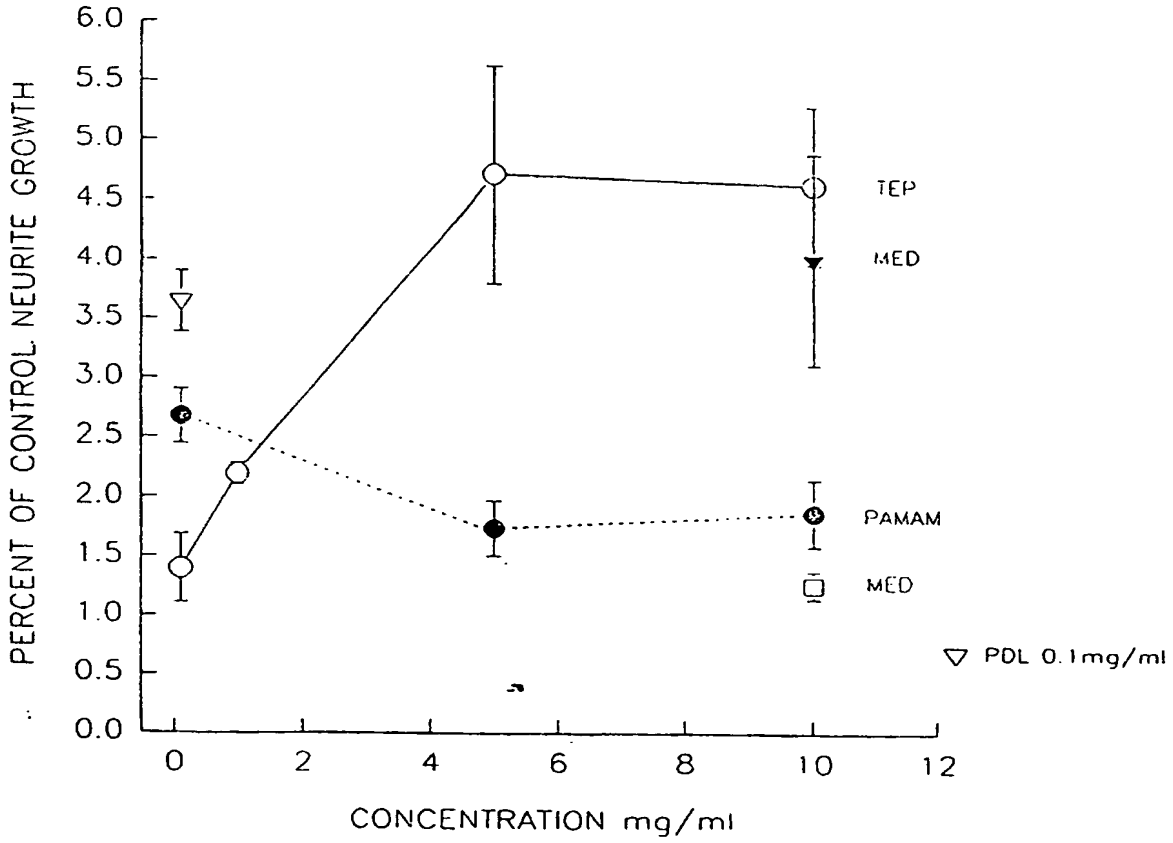


FIGURE 3

INTERNATIONAL SEARCH REPORT

Interna al Application No
PCT/CA 97/00437

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C08B37/16 A61K31/715

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C08B A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ANGEWANDTE CHEMIE. INTERNATIONAL EDITION, vol. 30, no. 1, 1991, pages 78-80, XP000606849 GADELLE A ET AL: "SELECTIVE HALOGENATION AT PRIMARY POSITIONS OF CYCLOMALTOOLIGOSACCHARIDES AND A SYNTHESIS OF PER-3,6-ANHYDRO CYCLOMALTOOLIGOSACCHARIDES" see page 79, right-hand column, line 3-20 ---	1-10
Y	CARBOHYDRATE RESEARCH, vol. 160, 1987, AMSTERDAM NL, pages 171-184, XP002039795 DE-PEI LU ET AL.: "Synthesis of 6-Deoxymaltooligosaccharides and a study of their lipid-binding properties." see page 172, paragraph 3 --- -/--	1-10

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
5 September 1997	30.09.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Lensen, H

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Intern · al Application No
PCT/CA 97/00437

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CARBOHYDRATE RESEARCH, vol. 228, no. 1, 10 April 1992, pages 307-314, XP000267124 BAER H H ET AL: "IMPROVED PREPARATION OF HEXAKIS(6-DEOXY)CYCLOMALTO-HEXAOSE AND HEPTAKIS(6-DEOXY)CYCLOMALTOHEPTAOSE" see page 307, last paragraph	1-10
A	TETRAHEDRON LETTERS, vol. 35, no. 26, 1994, OXFORD GB, pages 4489-4492, XP002039796 KARIN S. AKERFELDT ET AL.: "Synthesis and Per-Functionalization of Heptakis(6-O-carboxymethyl-2,3-di-O-methyl)cyclomaltoheptaose."	
A	EP 0 627 446 A (COMMISSARIAT A L'ENERGIE ATOMIQUE)) 7 December 1994	
A	US 5 464 827 A (RICHARD M. SOLL) 7 November 1995	
A	JOURNAL OF ORGANIC CHEMISTRY, vol. 61, no. 3, 9 February 1996, EASTON US, pages 903-908, XP002039797 PETER R. ASHTON ET AL.: "Amino Acid Derivatives of Beta-Cyclodextrin."	
A	STARCH STARKE, vol. 42, no. 11, 1 November 1990, pages 447-449, XP000160863 SZURMAI Z ET AL: "HALOGEN AZIDE DISPLACEMENT TO PREPARE SOME SYMMETRICALLY SUBSTITUTED SS-CYCLODEXTRIN DERIVATIVES"	

2

INTERNATIONAL SEARCH REPORT

...formation on patent family members

Intern - al Application No
PCT/CA 97/00437

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 627446 A	07-12-94	FR 2705963 A	09-12-94
		JP 7149784 A	13-06-95
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US 5464827 A	07-11-95	AU 2466795 A	15-01-96
		CA 2193086 A	28-12-95
		EP 0766699 A	09-04-97
		WO 9535322 A	28-12-95